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A Solid State Duplexer Switch for HF Radar

[Unclassified Title]

W. C. Headrick, R. A. Herring, J. P. Wood, and E. N. Zettle

Radar Techniques Branch
Radar Division

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ABSTRACT
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A problem area in the operation of the NRL hf radar has been that of satisfactory duplexing at 120 kw average and 5 Mw peak power level. The use of silicon diodes as switching elements in a balanced duplexer has been investigated, with such a system having been in use for over one year. Techniques have been devised for supplying appropriate bias for both transmit and receive periods. The results of the investigation show that the silicon diodes provide an adequate solution to the duplexing problems. Pulse to pulse recovery time and switch impedance jitter are negligible; the recovery time is 300 μs and could be further improved.

PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing on this and other phases.

AUTHORIZATION

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AF MIPR (30-602)-63-2928, 2929, 2995

Manuscript submitted October 7, 1964.

A SOLID STATE DUPLEXER SWITCH FOR HF RADAR
[Unclassified Title]

INTRODUCTION

One of the major problem areas in the operation of the NRL hf radar at the Chesapeake Bay Annex has been that of satisfactory antenna duplexing at a power level of 120 kilowatts average and 5 megawatts peak. Figure 1 shows the balanced duplexer configuration that was developed by Metcom, Inc., for the original high-power installation. During the transmitting period the inner and outer conductors of the coaxial lines that connect couplers 1 and 2 are shorted at points A and B by switching elements with the result that essentially all the power from the transmitter is delivered to the antenna. During the receiving period the shorts are removed from A and B and signals from the antenna are delivered to the receiver.

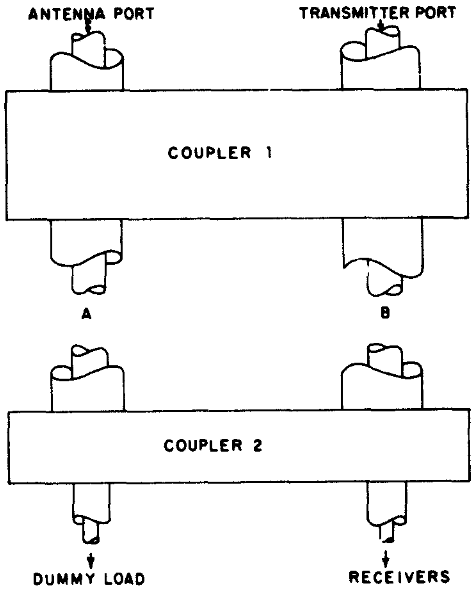


Fig. 1 - Balanced duplexer coupler arrangement. During the transmitting period the inner and outer conductors of the coaxial lines are shorted at A and at B with switching elements.

Initial high-power operation was attempted with gas tubes in the lines at A and B of Fig. 1, but this failed to yield satisfactory performance because the protection was insufficient and the current density was beyond the capacity of the tubes. As a consequence Metcom installed tuned line sections between the gas tubes and points A and B, which made the duplexer a narrow-band device even though the couplers had a two-to-one frequency range. A period of operation with the gas tubes showed several deficiencies such as the following: tube life was generally short, ranging from a few hours to a few hundred hours; recovery time at best was about 1 millisecond, and became longer with tube aging; and the line sections needed to be retuned with every change in operating frequency. Another even more serious defect in the gas tube operation was that both the low impedance across the line during transmitting time and the high impedance during receiving time would vary from pulse to pulse. The variations in the low impedance (or short) resulted in changes in the power transmitted from pulse to pulse that in effect gave a noise modulation to the clutter returns. The high impedance variations were evidenced as a jittering recovery time that noise-modulated the returned signals. Since successful operation of the hf radar requires working with signal-to-clutter ratios in excess of 60 db, any self-generated noise like the above that was not more than 60 db lower than the clutter was disastrous.

Use of silicon diodes for the switching element has provided a solution to most of the problems given above. The diodes used have a low rf impedance to large signals when operated with zero bias or forward bias yet have a comparatively high impedance to small signals when reverse biased. Further, with appropriate circuitry and cooling they can be placed in direct connection with the inner and outer conductors of the coaxial lines without the use of tuned line sections.

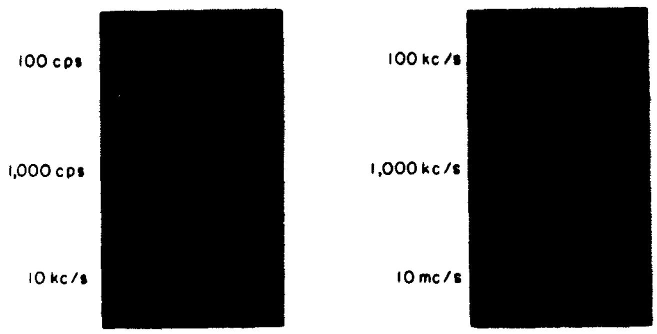


Fig. 2 - Waveforms of the current through an RCA 1N1206RA diode with zero bias

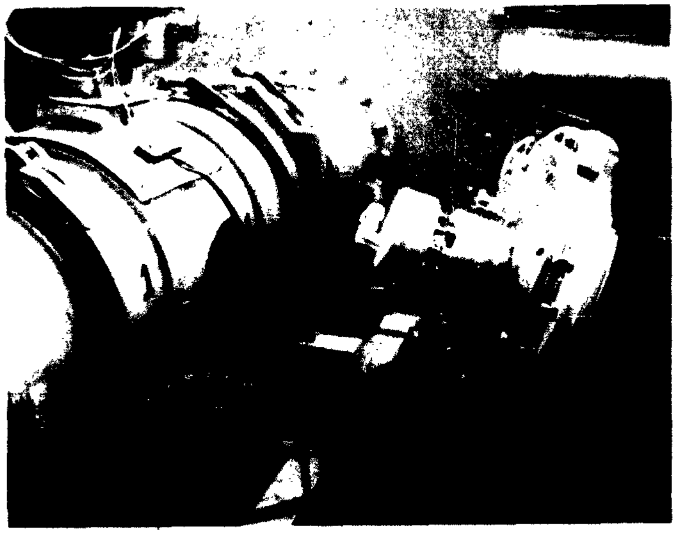
Table 1
Typical Values Measured at 30 Mc/s of the Capacitance and Parallel Resistance for an RCA 1N1206RA Diode When Reverse Biased

Bias (volts)	Capacitance ($\mu\mu$f)	Resistance (ohms)
3	141	224
6	104	419
10	82	703
30	51	2070
100	29	7250
200	21	17,470

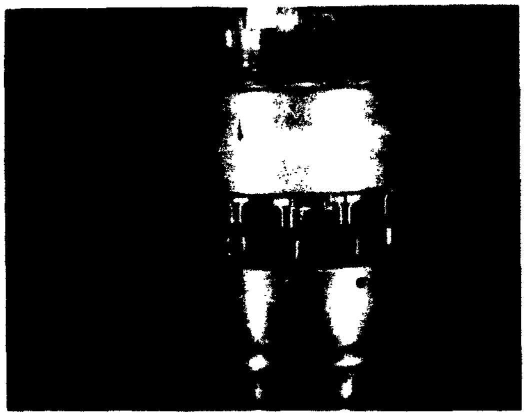
Figure 2 shows waveforms of the current through an RCA 1N1206RA diode with zero bias at various frequencies. Table 1 gives measured values of capacitance and resistance for a typical 1N1206RA diode when it is reverse biased.

EQUIPMENT AND OPERATION

Four diode mounts are used, with two mounts inserted in each line section at the switch position between the two couplers of Fig. 1. The portion of the mount that accepts the stud ends of the four diodes per mount is water cooled. A blower fastened to the line section forces air over the diode cases and pin ends. Figure 3 shows one of the mounts and Fig. 4 shows the mounts in position. The electrical circuit for one mount is given in Fig. 5.



(a) Mount beside line section



(b) Diodes in the diode mount

Fig. 3 - Diode mount

Fig. 4 - Duplexer arm with the two diode mounts in position

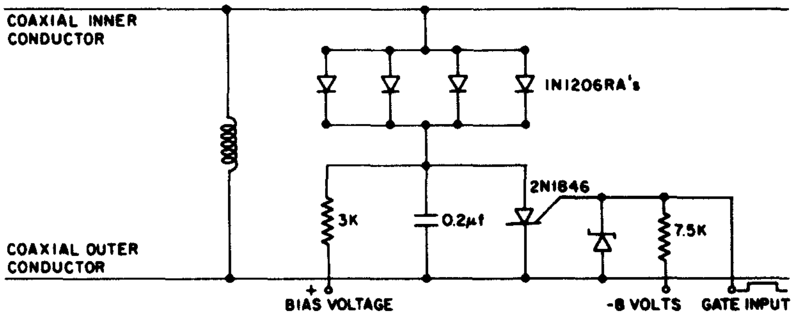


Fig. 5 - Electrical circuit of a diode mount in position

The 2N1846 shown in the circuit diagram is a silicon controlled rectifier (SCR). It performs a dual function in that it removes the reverse bias from the 1N1206RA's when it is gated on and at the same time prevents a voltage buildup on the capacitor due to rf rectification by the 1N1206RA's. Prevention of a voltage buildup is necessary, even though the rectification efficiency is extremely low, because the peak rf current in each set of diodes runs as high as 600 amperes on occasion. The SCR bias with a zener diode from control element to cathode keeps the control element at cathode potential in the absence of a gate pulse. The zener diode also limits the value of the gate pulse to the zener breakdown voltage. The resistor in series with the 1N1206RA bias supply limits the current to a value less than the hold-in current for the SCR.

The mechanical construction of the mounts evolved from many experiments, with changes being incorporated with the least amount of redesign. The capacitor consists of 17 aluminum sheets separated with 2-mil sheets of Mylar dielectric. Efforts were made to keep the rf path impedance low in order to form as effective a short as possible, and to minimize I^2R heating. Electrical contacts from the mount to both the inner and outer conductors of the coaxial lines are through O-rings made of rf gasket material.

RESULTS

Approximately one year of operation with the above equipment has shown that in general the diode switches are satisfactory. There is no jitter to the recovery time. As operated the recovery time is 300 μs due to the RC time constant of the bias circuit, but this could be shortened to under 100 μs if it were desired. The impedance during rf conduction is constant from pulse to pulse. The bandwidth of the duplexer is now that of the couplers instead of that of a tuned line section. On the economic side the price of one 1N1206RA is about $5.00 while one gas tube costs $1200.

Although during tests on the diodes and under standard operating conditions many diodes failed, most of the failures were not due to limitations of the duplexer. A high percentage of the failures were due to malfunctions elsewhere in the system. The most common of these would occur during the process of changing or dividing the prf. At this time a failure would occur because an rf pulse was sent to the duplexer without the accompanying gate pulse to remove the diode reverse bias, or failure would occur because a group of spurious triggers would originate a number of rf pulses much closer spaced than any normal prf. The latter condition resulted in momentarily running the average power up by a factor of 3 or 4, which was enough to cause failure. In connection with diode failure there are two things that should be stressed. One is that during the time of high rf conduction, the diodes are very sensitive to a dc reverse bias. It was noted in one test that a change in reverse bias from 4 to 6 volts lowered the no-failure power operating level by 6 db. The other is that the diodes need sufficient cooling. It was found that operation at elevated temperatures made the diodes more prone to failure from overloads and materially shortened their life. A fortunate feature of a diode failure is that it fails shorted rather than open. This tends to protect the other diodes and does give protection against receiver front-end burnout.

Figure 6 gives loss in received signal due to insertion of diodes and mounts. The data for Fig. 6 were taken with all coupler ports terminated in 50 ohms and the transmitter off. Under power the loss at 27 Mc/s will be 1 db higher due to diode heating, but this differential as well as the total loss become less as frequency is reduced and are negligible at 13.5 Mc/s. Table 1 shows that the loss is principally a reflection loss, due mainly to diode capacity across the line rather than to the resistive component of the diode impedance. Figure 7 is included to show how insertion loss changes as the diode reverse bias is varied.

RECOMMENDATIONS

The use of silicon diodes in a balanced duplexer is an adequate solution to the switching problem; however, it is felt that the present equipment could be improved upon in several respects. A different design of the hardware should lower the impedance of the rf path by shortening the length of high-current-carrying parts and by using higher conductivity materials. Attention should be given to a method for easily changing any diodes that fail.

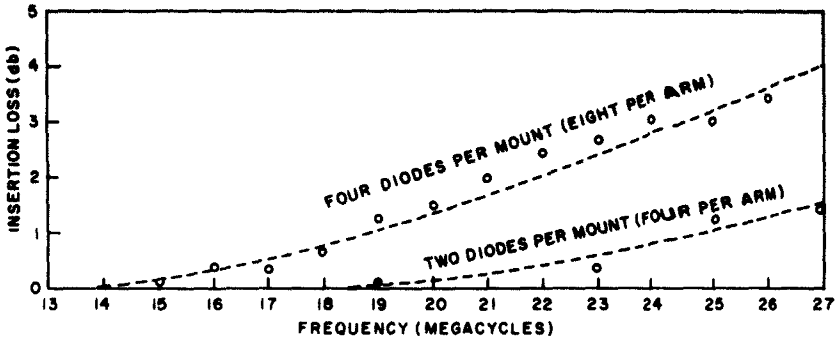


Fig. 6 - Loss in the received signal due to the insertion of a diode mount with the diodes biased with 150 volts and all ports terminated in 50 ohms

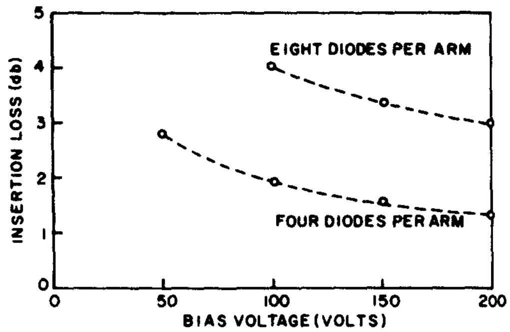


Fig. 7 - Effect of the diode reverse bias on the insertion loss at 26.6 Mc/s with all ports terminated in 50 ohms

While many types of diodes were tested, most were of the same general class as the RCA 1N1206RA that is now in use. Further search might yield a diode with better characteristics. An improvement on the diodes now in use could be made by packaging the diode such that both sides of the junction could be placed against a heat sink. With better cooling fewer diodes would need to be used, thus lowering the total capacity in shunt with the line.

Ideally the bias circuitry should put the required reverse bias voltage on the diodes during receiving time and should not only remove the reverse bias but actually place a forward bias on the diodes during the transmitting period. If this proves impractical, the reverse bias that tends to build up during the transmitting period should be kept to a minimum. The silicon controlled rectifiers now used are somewhat temperature sensitive. Both firing point and holdoff voltage change with temperature. One of the gate-turn-off devices would probably be superior in this respect and would allow better control of the reverse bias at the end of the transmitting period.

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13. ABSTRACT

A problem area in the operation of the NRL hf radar has been that of satisfactory duplexing at 120 kw average and 5 Mw peak power level. The use of silicon diodes as switching elements in a balanced duplexer has been investigated, with such a system having been in use for over one year. Techniques have been devised for supplying appropriate bias for both transmit and receive periods. The results of the investigation show that the silicon diodes provide an adequate solution to the duplexing problems. Pulse to pulse recovery time and switch impedance jitter are negligible; the recovery time is 300 μs and could be further improved. [Secret Abstract.]

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A problem area in the operation of the NRL hf radar has been that of satisfactory duplexing at 120 kw average and 5 Mw peak power level. The use of silicon diodes as switching elements in a balanced duplexer has been investigated, with such a system having been in use for over one year. Techniques have been devised for supplying appropriate bias for both transmit and receive periods. The results of the investigation show that the silicon diodes provide an adequate solution to the duplexing problems. Pulse to pulse recovery time

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2. Electronic switches – Design

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Thank you,

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